Growth, fruit size, yield performance and micronutrient status of plum trees (*Prunus domestica* L.)

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ABSTRACT

This study was carried out to determine the growth, fruit size, yield performance and leaf micronutrient status of four Serbian cultivars originated from Fruit Research Institute in Cacak [Čačanska rana (ČRA), Čačanska lepotica (ČLE), Čačanska najbolja (ČNA), Čačanska rodna (ČRO)] and six introduced cultivars [Ruth Gerstetter (RGE), Stanley (STA), Agen (AGE), Opal (OPA), Bluefree (BLU), Violeta (VIO)] grafted on suckers of local plum cultivar Belošljiva with high density under limited soil conditions of Cacak (Western Serbia). The highest trunk cross sectional area (TCSA) was recorded in ČNA and the lowest in ČLE. The higher fruit weight (FW) was registered in ČRA and lower in AGE. The most productive cultivars per tree and hectare were STA and ČRO, respectively. All cultivars showed significant differences regarding leaf micronutrient concentration and deviation to the optimum concentration (DOP). ČRO and AGE showed a wider and best balance in leaf nutritional values, respectively.

Keywords: DOP index; HDP system; leaves; microelements; vigour

In Serbia, the plum (*Prunus domestica* L.) was the most spread species, because of the good climate conditions, the fruit value (energetic, nourishing, dietetic etc.) and was further considered a traditional species. In this area, plums have high economical, social and supply importance. Plum fruit are used for fresh consumption as well as for drying. Also, main processed products made from plums include compotes, mousse, pulp, candied fruit, frozen fruit, jams, jelly products and traditional Serbian plum alcoholic beverages 'Šljivovica' (Milosevic et al. 2010a). The total area of plum in Serbia reached over 200 000 ha which produced 662 631 t in 2009 (Faostat 2011). However, Serbian plum production is characterized by extensive growing technology, low unstable yields, low fruit quality, multitude of cultivars and PPV-induced problems (Milosevic et al. 2010b). The most important plum-growing area in Serbia is the Region of Cacak. The soils of this region are low in organic matter content and acidic in reaction and these conditions are not favorable to nutrients availability (Miloševič and Miloševič 2011a). Since the soils in these plum orchards are of poor physical, chemical and biological properties, appearance of nutrients deficiencies symptoms and responses to added nutrients indicated the prevalence of nutritional disorders of macronutrients and micronutrients. Earlier surveys of fruit orchards indicated low soil pH and deficiencies of nutrients in Serbian soils (Milosevic and Milosevic 2011b). Due to nutrient deficiency and/or excess, plum orchards are now turning into unproductive plantation, producing limited vegetative growth, low yield and poor fruit quality (Milosevic and Milosevic 2009).

Leaves analyses, as an early and/or late tool to allow the diagnosis of potential deficiencies or excesses, were studied (Leece 1975, Sánchez-Alonso and Lachica 1987, Singh-Sidhu and Kaundal 2005). However, little information is available on the planting density influence on plum scion leaf micronutrient concentration. From this reason, it is of interest to study the effect in plum cultivars.

The objective of this work was to evaluate the tree growth, yield, fruit size and leaf micronutrient status at 120 DAFB of ten plum cultivars

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and to define the optimum leaf concentrations of micronutrients as a function of optimal tree growth, fruit size and yield in young plum orchard on sandy-loam and acidic soil under high density planting system.

MATERIAL AND METHODS

Plant material. The four Serbian [Čačanska rana (ČRA), Čačanska lepotica (ČLE), Čačanska najbolja (ČNA), Čačanska rodna (ČRO)] and six introduced [Ruth Gerstetter (RGE), Stanley (STA), Agen (AGE), Opal (OPA), Bluefree (BLU), Violeta (VIO)] plum cultivars, grafted on suckers of local plum cultivar Belošljiva (*P. domestica* L.), were evaluated in 2006 and 2007. The orchard was established in 2001.

Field trial. The studies were conducted at Prislonica (43°57'N, 20°26'E, 344 m a.s.l.) near Cacak (Western Serbia) on a cambisol soil. Trees were planted at high-density planting (HDP) system with planting spaces of 4 m × 2 m. Training system are Spindle bush. The orchard was fertilized on the basic local empiric criterion with 400 kg of compound NPK (15:15:15) mineral fertilizer in fall and with 300 kg/ha of calcium ammonium nitrate (CAN) contained 27% of N_{TOT} to the onset of the growing cycle. Trees were grown under standard practice for HDP, except irrigation.

Soil mineral status and weather conditions. Soil mineral analyses were carried out in autumn 2005 and 2006 i.e. before fertilization. Soil samples were taken from 0–30 cm depths. Soil solution was prepared with suction method. Methodology for soil mineral status and results of soil chemical analysis are previously published by Milošević and Milošević (2011a).

Weather conditions of Cacak are characterized by the average annual temperature of 11.3°C and total annual rainfall of 690.2 mm.

Measurement of the tree growth, fruit weight and yield properties. Tree growth was evaluated through trunk cross-sectional area [TCSA (cm^2)]. The data for TCSA (trunk diameter) were obtained from five trees per cultivar in two replications at 10 cm above the bud union and calculated at the end of 2007. Ruler and digital caliper Starrett 727 Series (Athol, New England, USA) were used.

For a period of two harvest seasons, 25 fruits from each cultivar of each of two replicates were collected and FW (g) was measured using a Tehnica ET-1111 technical scale (Iskra, Kranj, Slovenia). An ACS System Electronic Scale (Zhejiang, China) was used to measure yield per tree (YT) and hectare (YH) (kg). Yield efficiency (YE) (kg/cm^2) is the ratio between the YT and TCSA in 2007.

Leaf mineral analysis. Leaf micronutrient concentrations were determined in 2007. Sampling was done at 120 DAFB. Leaf samples were collected from the middle part of one-year-old shoots of trees in five blocks for each cultivar. Cleaning, drying, grinding and storing of samples were carried out in accordance with the procedure described by Chapman (1964). Methodology for leaf mineral status and results of their chemical analysis are previously described (Miloševic and Miloševic 2011b).

Deviation from optimum percentage (DOP index). The DOP index was estimated for the diagnosis of the leaf nutrient status of the trees (Montañés et al. 1991), and was calculated from the leaf analysis at 120 DAFB by the following mathematical equation:

$$DOP = \frac{C \times 100}{C_{ref}} - 100$$

Where: C is the minor element concentration in the sample to be studied, and C_{ref} is the minor nutrient content considered as optimum, both values given on a dry matter basis. The C_{ref} has been taken from optimum values, proposed by Heckman (2004) for micronutrients. The ΣDOP is obtained by adding the values of DOP index irrespective of sign.

Statistical analysis. All data in the present study were subjected by analysis of variance (ANOVA) and means were separated by the Duncan's multiple range tests (DMRT) at $P \leq 0.05$. The figures are performed by the Excel program.

RESULTS AND DISCUSSION

Tree growth, fruit weight and yield properties. After six years of growth, cultivars produced significantly different TCSA (Figure 1). The highest TCSA was registered in ČNA and RGE, and the lowest in ČLE. These results indicated that ČNA, ČRA, and RGE have the most vigour trees, ČRO, AGE and ČLE being cultivars with dwarfing trees, whereas the rest of cultivars have moderate tree growth. This corresponds to results obtained by other authors (Sosna 2002, Vitanova et al. 2004). Meland (2005) found that OPA was the most vigorous. Similarly, BLU grew vigorously in our trial, but was reported as slow growing in the Czech Republic (Blažek et al. 2004). Generally, our data were in a good agreement with results of above authors, although ČLE in our study had low tree growth. The differences may be due to a better or

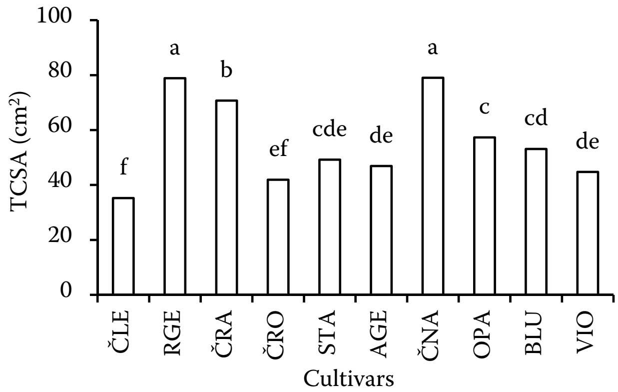

Figure 1. Final trunk cross sectional area (TCSA) of ten plum cultivars (values from 2007). The different letters on the top of columns indicate significant differences among cultivars at $P \leq 0.05$ by DMRT. ČRA – Čačanska rana; ČLE – Čačanska lepotica; ČNA – Čačanska najbolja; ČRO – Čačanska rodna; RGE – Ruth Gerstetter; STA – Stanley; AGE – Agen; OPA – Opal; BLU – Bluefree; VIO – Violeta

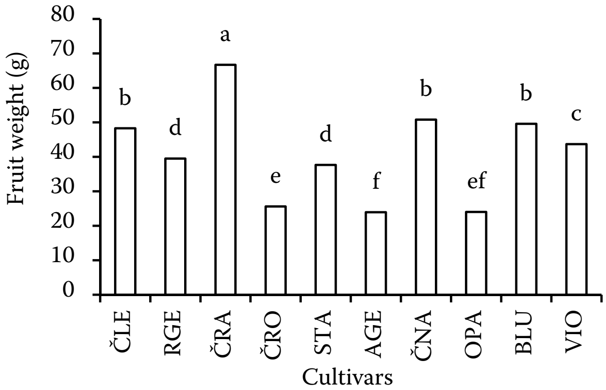

Figure 2. Fruit weight of ten plum cultivars (mean for 2006 and 2007). For explanation of letters on the top of columns and abbreviations see Figure 1

worse adaptation of this cultivar to a soil and climate conditions, rootstocks and cultural practices used, as previously reported by Grzyb et al. (1998).

The FW was dependent on the cultivars (Figure 2). The biggest fruits were recorded with ČRA, and the next according to mean FW were ČNA, BLU and ČLE, although differences among them were not significant. The next in sequence were VIO, RGE and STA. On the contrary, the smallest mean FW belonged to ČRO, OPA and AGE. All reminding cultivars could be classified like plums with medium fruit size (Blažek and Pištěková 2009), except ČRA and ČNA. These cultivars could be classified as large fruits cultivars on the basis of summarized results (Blažek et al. 2004). Mean FW and its variation recorded in this trial corresponded quite well to data observed in literature (Halapija-Kazija et al. 2009). A greater disagreement in comparison to published data could be stated in BLU that should have possessed very large fruits, sometimes reaching weights up to 70 g (Blažek and Pištěková 2009). This result indicated that some plum cultivars on Belosljiva had the tendency to the decrease mean FW, particulary on sandy-loam soils, in accordance with the studies undertaken by Grzyb et al. (1998).

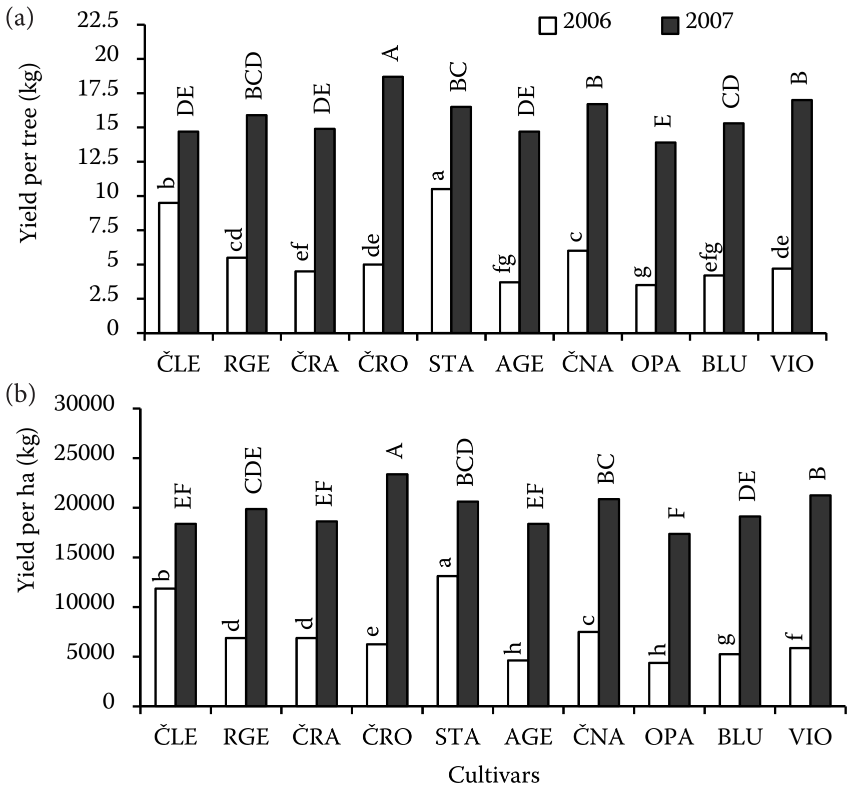

Figure 3. Yield per tree (a) and yield per hectare (b) of ten plum cultivars in 2006 and 2007. Different lower-case letters on the top of columns represent significant differences among cultivars in 2006 and capital letters represent significant differences among cultivars in 2007 at $P \leq 0.05$ by DMRT. For explanation of abbreviations see Figure 1

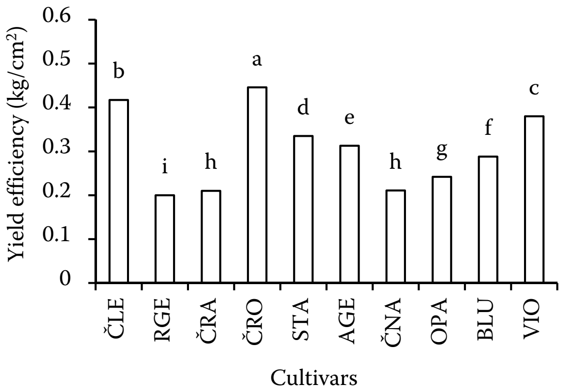

Figure 4. Yield efficiency of ten plum cultivars. For explanation of letters on the top of columns and abbreviations see Figure 1

Data in Figure 3a showed that the highest YT in 2006 registered in trees of STA, folowed by ČLE, ČNA etc, whereas the lowest YT produced trees of AGE and OPA. Considering YT in the fifth years after planting, STA, ČLE and ČNA were the most productive cultivars, whereas AGE and OPA the least. In 2007, the best YT was recorded in ČRO, VIO and ČNA, while the poorest YT registered in OPA. Generally, data show a significant increase of YT obtained with 2007 compared to those 2006. Similarly, YT positively corresponding to the YH (Figure 3b). The highest YH was recorded in STA in 2006 and in ČRO in 2007. The lowest values were recorded in OPA in both years although between OPA and AGE in 2006 differences were insignificant.

The differences among cultivars for YE were also significant (Figure 4). The highest value was recorded in ČRO, followed by ČLE, VIO and STA. The lowest YE were registered on trees of ČNA, ČRA and RGE. The most productive cultivars were ČRO and VIO, and the lowest yield was produced by OPA. This confirms previous reports showing that the higher YE of ČRO resulted from its lower vigour and higher bearing potential (Milosevic et al. 2009). Contrary, the lowest YE found on OPA. This is probably due to their high vigour and so high TCSA (Meland 2005, Peppelman et al. 2007). Also, Meland (2005) reported that OPA in the fourth leaf in HDP had significantly smaller fruits, and trees gave 15 t per hectare. Our YH for this cultivar was higher than those obtained by Meland (2005), but in the sixth year after planting. In general, our data for YT, YH and YE are similar to those published by Halapija-Kazija et al. (2009) and Milosevic et al. (2009) with similar group of plum cultivars and inferior to the results obtained by Blažek and Pištěková (2009). Low values of YE and high TCSA values showed that Belošljiva rootstock in our study influenced relatively high vigour. It seems that Belošljiva is unsuitable rootstock for HDP system, as previously reported by Milosevic et al. (2009).

Leaf micronutrients status at 120 DAFB. Significant differences were observed among cultivars for leaf Fe, Mn, Zn, and B concentration, except Cu (Table 1).

Regarding leaf Fe, values were higher in ČRA and BLU, although differences between them were insignificant. Intermediate values were in ČNA, VIO and RGE, whereas lower values were in STA and AGE. The highest leaf Mn was shown in BLU and the lowest in ČLE. Leaf Zn concentration was higher in OPA, intermediate in RGE and BLU, and lower in ČRA. Leaf B was higher on ČRO than on the rest.

Previous studies by several authors on plum also reported a high variability among cultivars

Table 1. Impact of plum cultivars on microelement concentrations of leaves at 120 DAFB

Cultivars	Microelements (mg/kg of dry mater)				
	Fe	Mn	Cu	Zn	B
Čačanska lepotica	228.1^{b}	57.6^{i}	5.5^{a}	61.3^{ef}	32.6^{g}
Ruth Gerstetter	199.4^{d}	87.4^{ef}	6.2^{a}	67.2^{de}	38.4^{e}
Čačanska rana	243.7^{a}	77.3^{g}	6.4^{a}	57.5^{f}	33.1^{fg}
Čačanska rodna	215.1^{c}	72.2^{h}	6.3^{a}	79.2^{bc}	53.7^{a}
Stanley	171.9^{f}	103.3^{c}	8.2^{a}	65.3^{def}	29.3^{h}
Agen	135.3^{g}	84.9^{f}	7.3^{a}	64.2^{def}	48.6^{b}
Čačanska najbolja	201.2^{d}	116.1^{b}	6.4^{a}	81.2^{b}	43.5^{d}
Opal	187.8^{e}	89.6^{de}	8.4^{a}	88.4^{a}	34.2^{f}
Bluefree	241.2^{a}	132.1^{a}	7.1^{a}	66.7^{def}	45.4^{c}
Violeta	201.1^{d}	92.2^{d}	7.2^{a}	72.3^{cd}	42.2^{d}

Data with the same letter(s) in columns are not significantly different at $P \leq 0.05$ by DMRT

Table 2. Impact of plum cultivars on DOP index and ΣDOP determined from leaf microelement concentrations at 120 DAFB

Cultivars	Microelements (mg/kg of dry mater)					
	Fe	Mn	Cu	Zn	B	ΣDOP
Čačanska lepotica	+30.3	–42.4	–50.0	+75.1	–23.3	221.1[b]
Ruth Gerstetter	+13.9	–12.6	–43.6	+92.0	–9.6	171.7[g]
Čačanska rana	+39.3	–22.7	–41.8	+64.3	–22.1	190.2[f]
Čačanska rodna	+22.9	–27.8	–42.7	+126.3	+26.3	246.0[a]
Stanley	–1.8	+3.3	–25.4	+86.6	–31.1	148.2[j]
Agen	–22.7	–15.1	–33.6	+83.4	+14.3	169.1[h]
Čačanska najbolja	+15.0	+16.1	–41.8	+132.0	–2.3	207.2[d]
Opal	+7.3	–10.4	–23.6	+152.6	–19.5	213.4[c]
Bluefree	+37.8	+32.1	–35.4	+90.6	+6.8	202.7[e]
Violeta	+14.9	–7.8	–34.5	+106.6	–0.7	164.5[i]

Leaf composition standards for plum cultivar trees, based on mid-shoot leaves sampled at 120 DAFB (Heckman 2004); (–) indicate lower content than optimum; (+) indicate higher content than optimum; the letter(s) in the latest column indicate significant differences between cultivars for ΣDOP at $P \leq 0.05$ by DMRT

regarding leaf Fe, Mn, Cu, Zn and B concentration (Sánchez-Alonso and Lachica 1987, Heckman 2004, Singh-Sidhu and Kaundal 2005). The significant differences were not observed among cultivars for Cu concentration in leaves. This may arise from the fact that the variation for foliar concentration of these elements is often quite narrow, as it has been previously mentioned (Leece 1975).

The micronutrient concentrations at 120 DAFB followed a decreasing order: Fe > Mn > Zn > B > Cu (Table 1). However, Heckman (2004) reported that optimal concentration of microelements in the plum leaves consider higher concentration of B than Zn, and we can say that imbalance existed in nutritional values for B and Zn. These results were also shown in previous works (Nasr et al. 1977).

DOP and ΣDOP index. Data in Table 2 showed that all cultivars had deviation to the normal amount of microelements at 120 DAFB. Fe concentrations were on the excess level, except for AGE and STA. In leaf of both cultivars leaf Fe were lower than normal (Leece 1975, Heckman 2004). The antagonistic effect of P on cationic micronutrients could be responsible to some extent of the low Fe concentration observed (Ankerman and Large 1977). A similar tendency was observed in an earlier study carried out in plum (Shear and Faust 1980). The Mn concentration was generally lower than optimum in all cultivars, except STA, ČNA and BLU. In the leaves of these cultivars, Mn was higher than normal. The Mn is a micronutrient that limits the normal growth fruit trees on calcareous soils and it is relatively immobile in the plant (Leece 1975). The low foliar Mn value was thought to be related to these physicochemical properties which give rise to an inadequate N metabolism (Sánchez-Alonso and Lachica 1987). Also, the Fe uptake may also be negatively affected by Mn, as previously reported (Singh-Sidhu and Kaundal 2005). Leaf Cu values were considered to be inadequate for all cultivars in our study, although the Cu deficiencies are extremely rare in plum orchards (Shear and Faust 1980). However, Reuther and Labanauskas (1966) reported that Cu deficiency symptoms occur most often on sandy soils, and acidic sands and soils heavily fertilized with nitrogen, as is the case in our study. The Zn concentration was higher than adequate in all cultivars, and these high values may be the consequence of an application of a fungicide with a high percentage of Zn, before leaf sampling, as previously reported (Zarrouk et al. 2005). ČRO, AGE and BLU have higher B concentration than adequate, while the rest of cultivars have lower values than normal. The deficiency of B in plum orchards may be due to low content of these nutrients in soils or the unfavorable physical-chemical properties of soils of the Cacak region. These results are in line with the early work of Tariq et al. (2008) and suggest that the growers should use B fertilizers in similar plum orchards.

Significant differences were observed among cultivars for ΣDOP index (Table 2). Results indicated that ČRO showed a wider balance in nutritional values, followed by ČLE, OPA, ČNA etc. On the other hand, AGE showed the best balance in these values among all cultivars. The high variability of ΣDOP index shown by leaf nutrient content has already been reported by Zarrouk et al. (2005) and Milosevic and Milosevic (2011a,b).

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